GEOMECHANICS GROUP @ UofT

Lassonde Institute
Innovation in Engineering Geoscience
University of Toronto

Three-dimensional observation of the fracture process zone in anisotropic granitic rock by x-ray CT scan and 3D stereo topometric cameras

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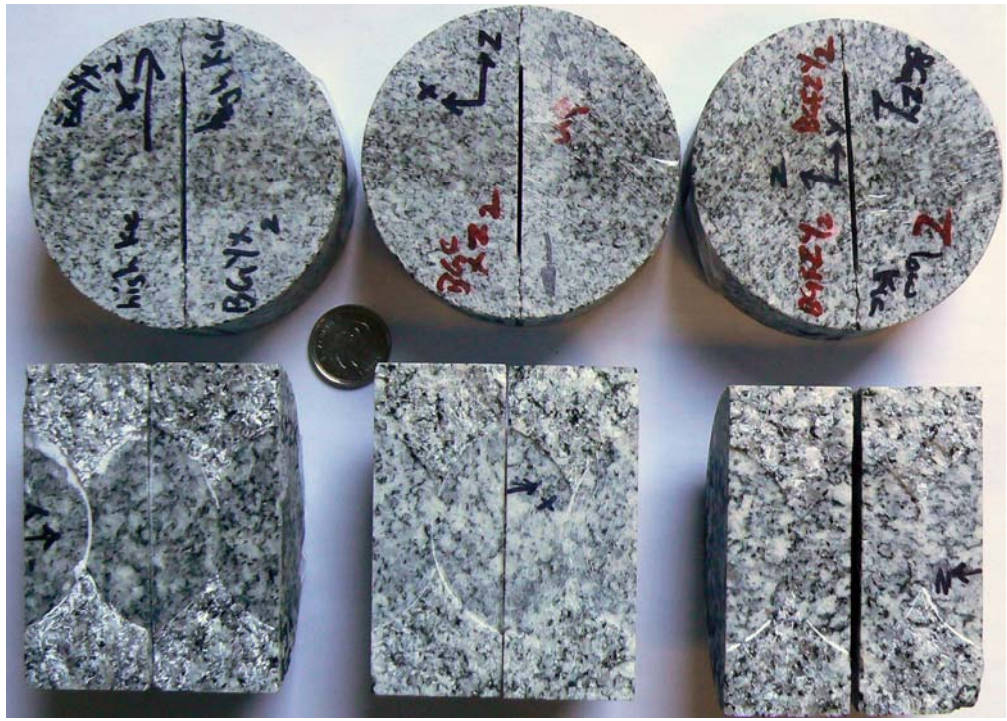
EURO-CONFERENCE OF ROCK PHYSICS AND GEOMECHANICS
Erice, Sicily, 26th September, 2007

Research objectives

Correlation of among roughness, toughness and microstructural fabric

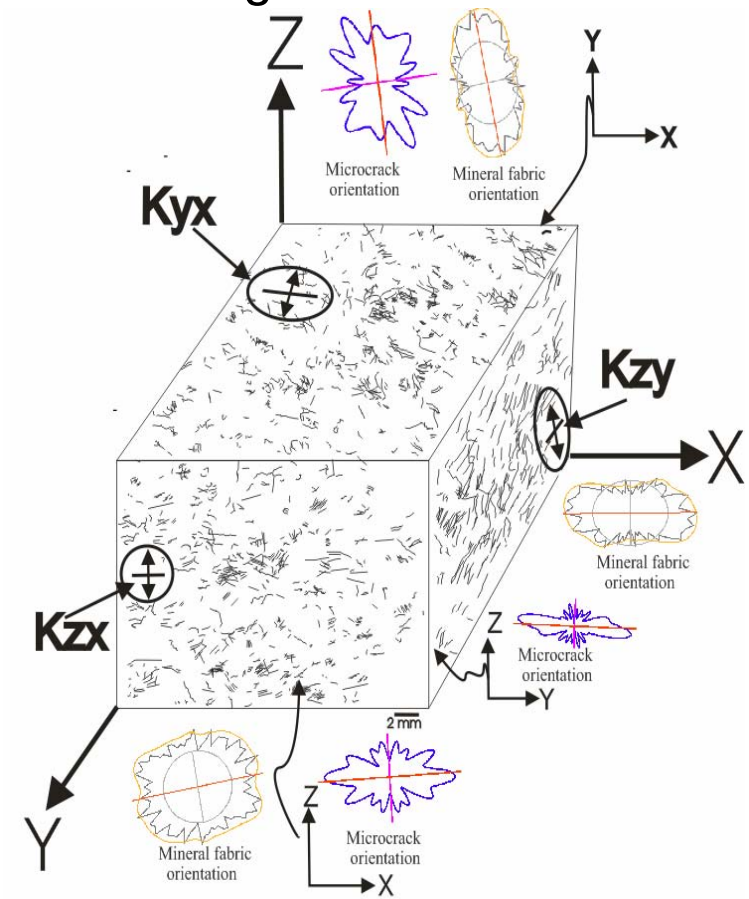
Barre granite



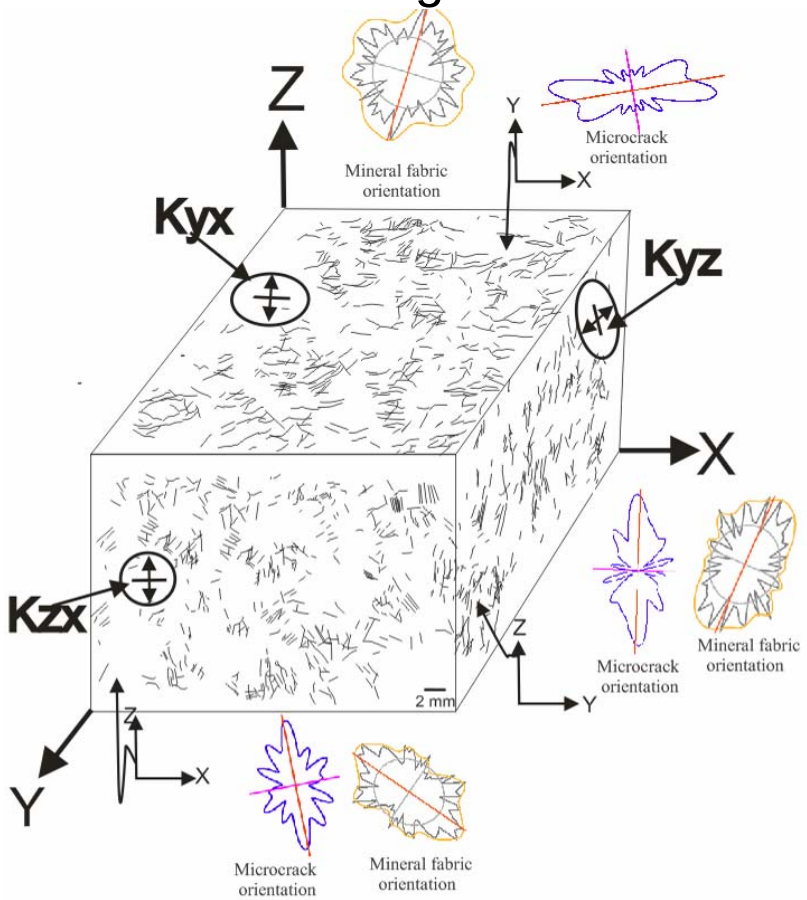
Stanstead granite

Basis for experimental set up and research objectives

Barre granite

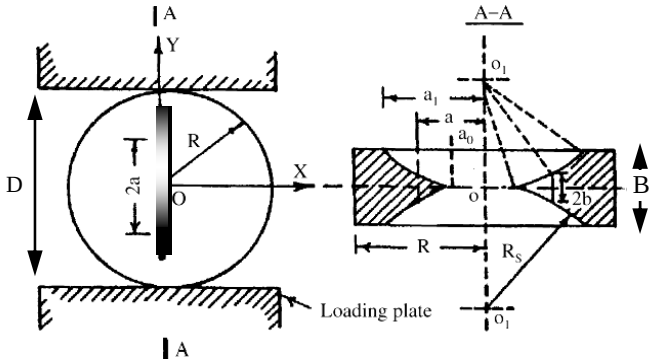


Stanstead granite



M.H.B. Nasseri and B. Mohanty, 2007, *Fracture toughness anisotropy in granitic rocks*, International Journal of Rock Mechanics and Mining Sciences, doi:10.1016/j.ijrmms.2007.04.005

Fracture toughness (K_{IC}) measurement



Dimensionless parameters

$\alpha_0 = a_0/R$ $\alpha_1 = a_1/R$ $\alpha_B = B/R$

Geometry of the Cracked Chevron Notch Brazilian Disc (CCNBD) specimen and related parameters (ISRM, 1995)

R = Radius of disc

B = Thickness of disc

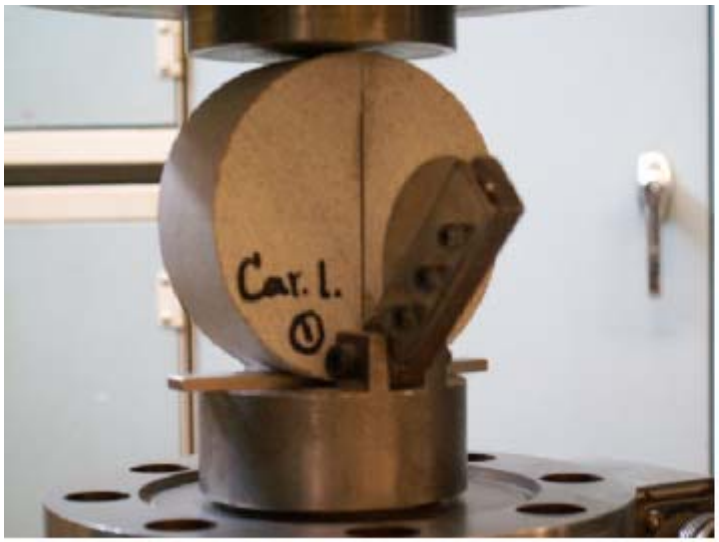
D = Diameter of disc

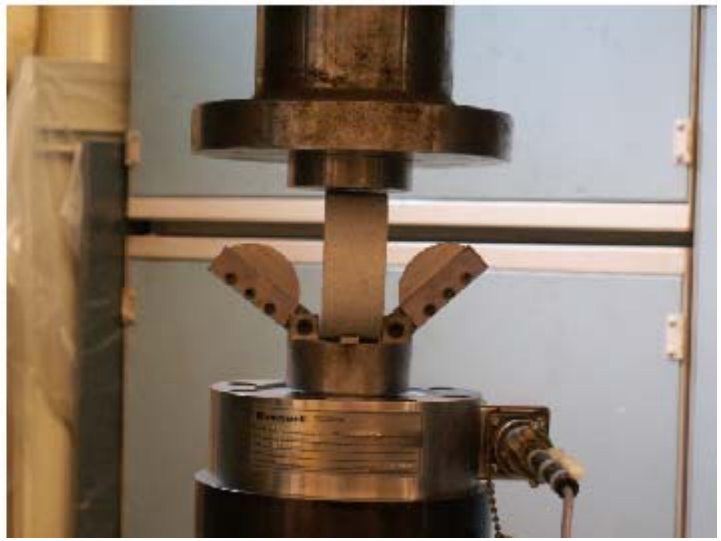
R_S = Radius of saw;

a = Length of crack

a_0 = Initial half length of chevron notch

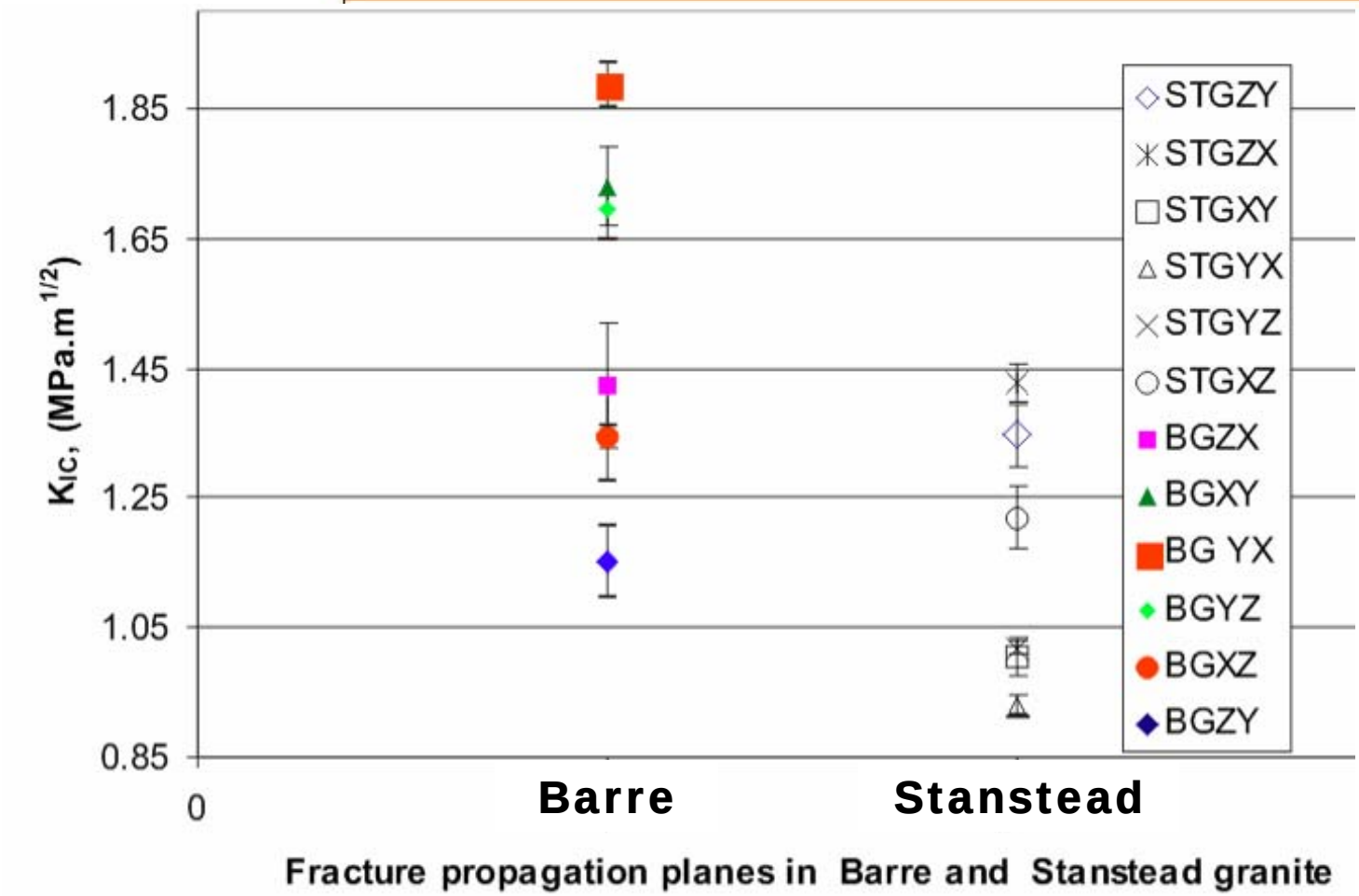
a_1 = Final half length of chevron notch





$$K_{IC} = \frac{P_{\max}}{B\sqrt{R}} Y^*_{\min}$$

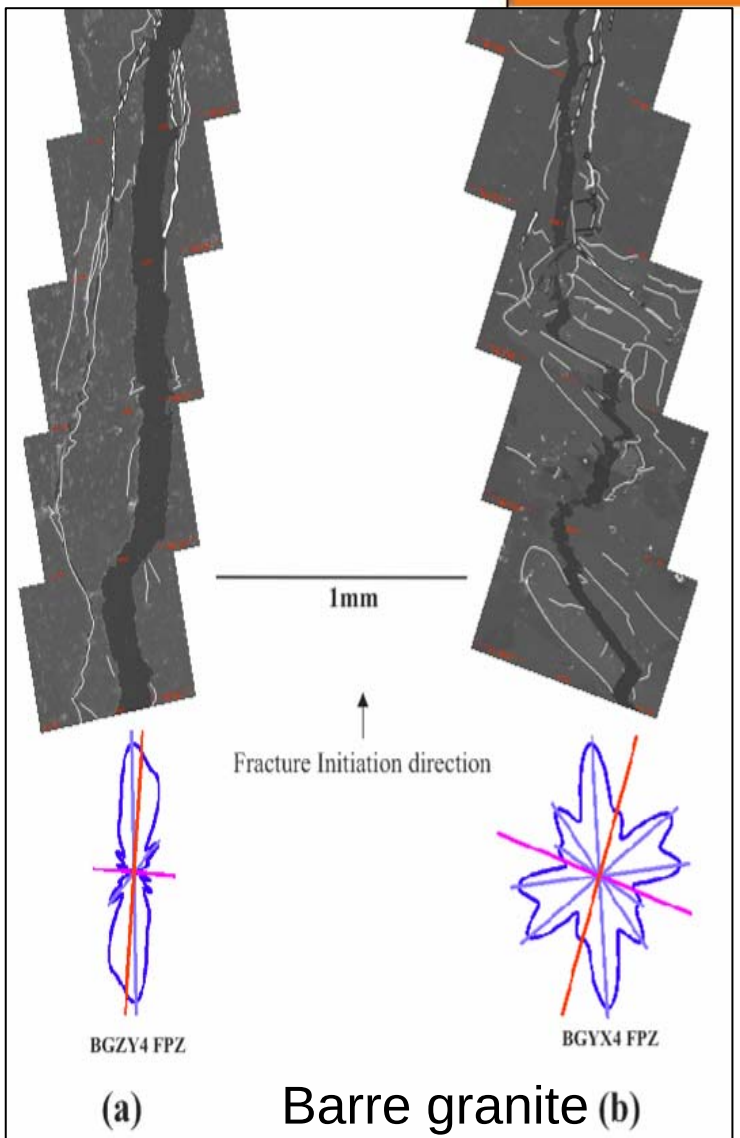
Results on variation of K_{IC} with respect to microstructural fabric directions



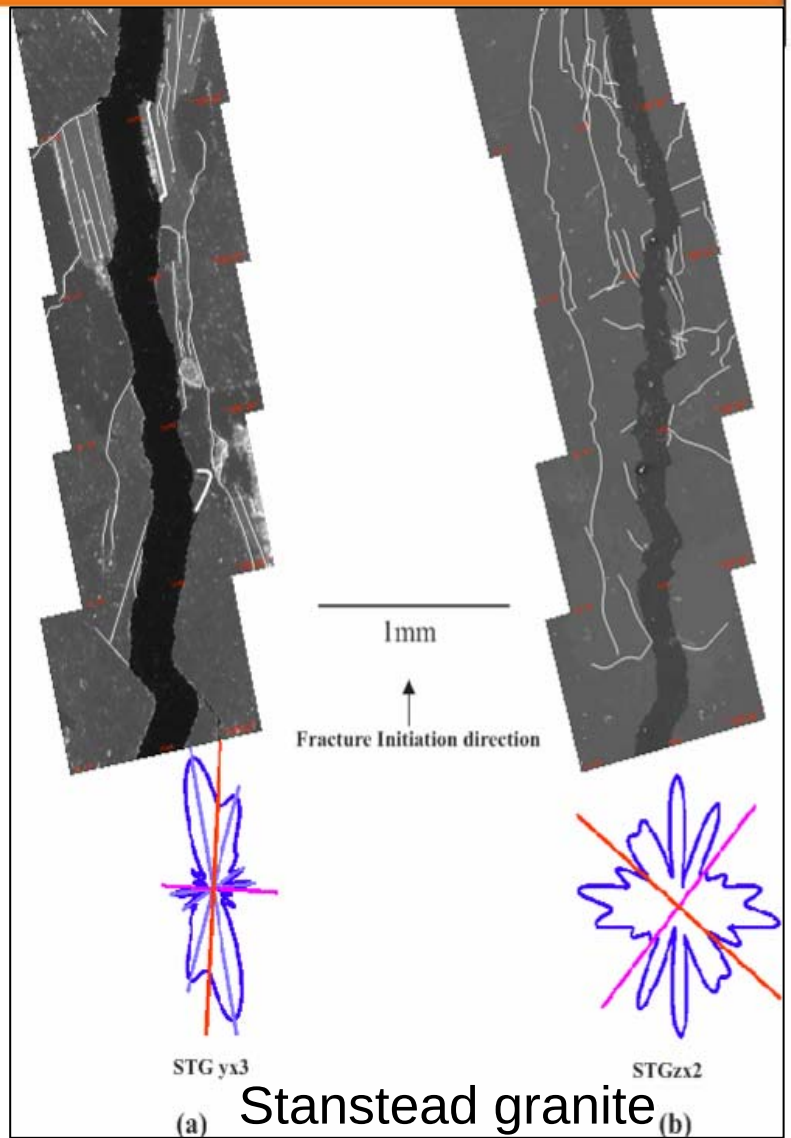
M.H.B. Nasseri, G. Grasselli, B. Mohanty, J. Wirth, M. Braun, 2007, *Experimental relationship between fracture toughness and fracture roughness in anisotropic granitic rocks*, Proc. 1st Canada US Rock Mech. Symp., 617-624

Note: Each point is calculated as the average of 5 experiments

Fracture process zone studies in SEM



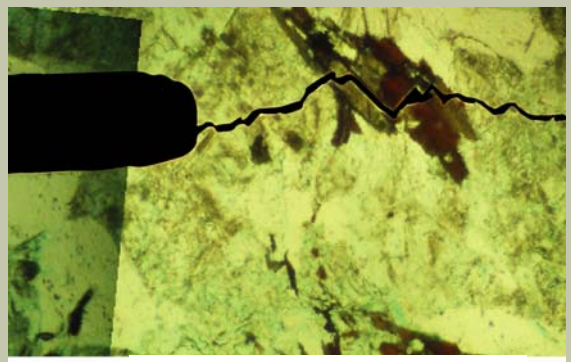
Barre granite



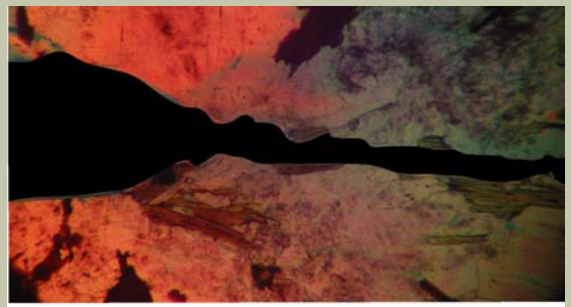
Stanstead granite

Influence of mineral composition & fracture toughness on fracture roughness

Barre Granite



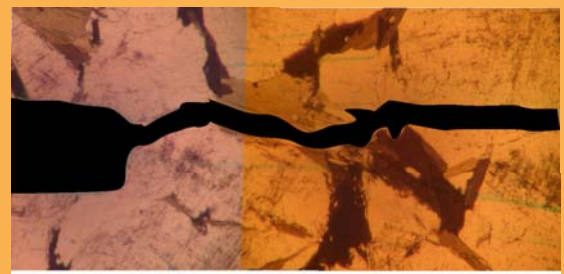
K_{xy}=1.89 MPa.m$^{0.5}$



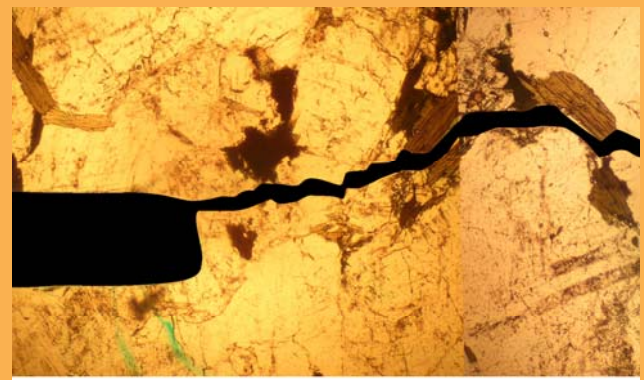
K_{zy}=1.14 MPa.m$^{0.5}$

	Quartz		Feldspar		Biotite	
	Av.G Size (mm)	%	Av.G Size (mm)	%	Av.G Size (mm)	%
XY	0.93	25%	1.10	75%	0.46	4%
XZ	0.95	31%	0.81	61%	0.43	6%

Stanstead Granite



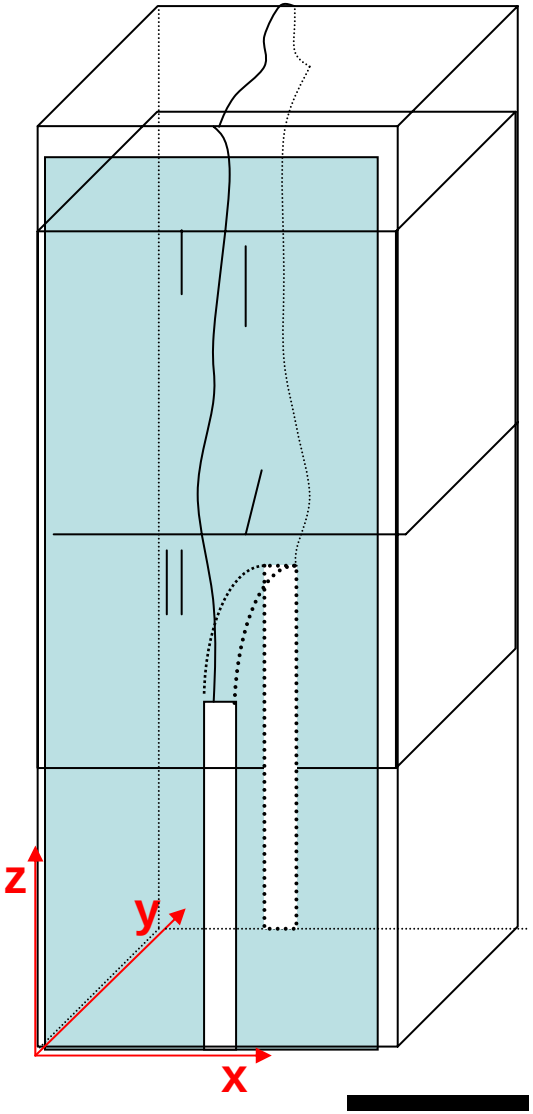
K_{yx}=0.93 MPa.m$^{0.5}$

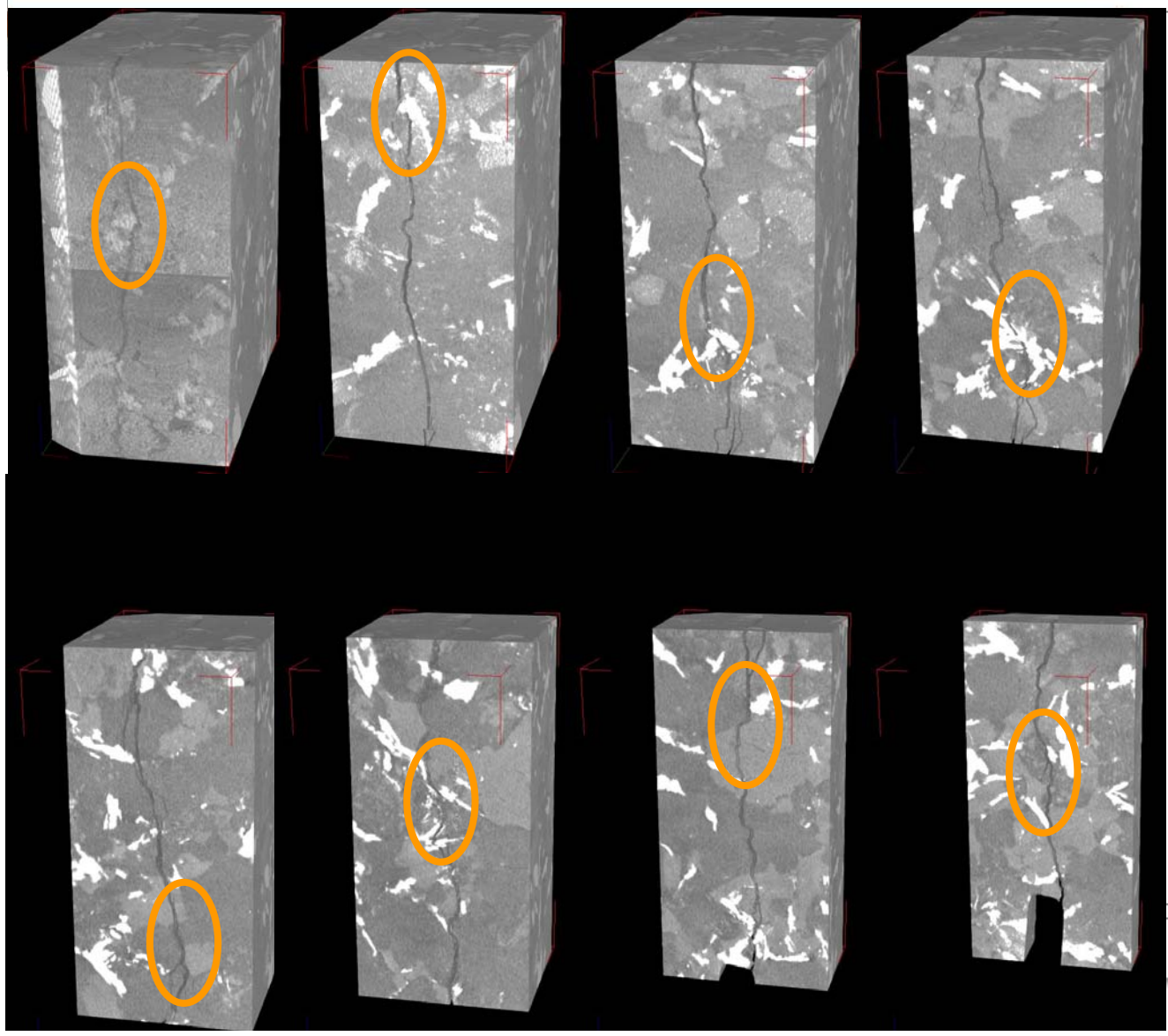


K_{zx}=1.43 MPa.m$^{0.5}$

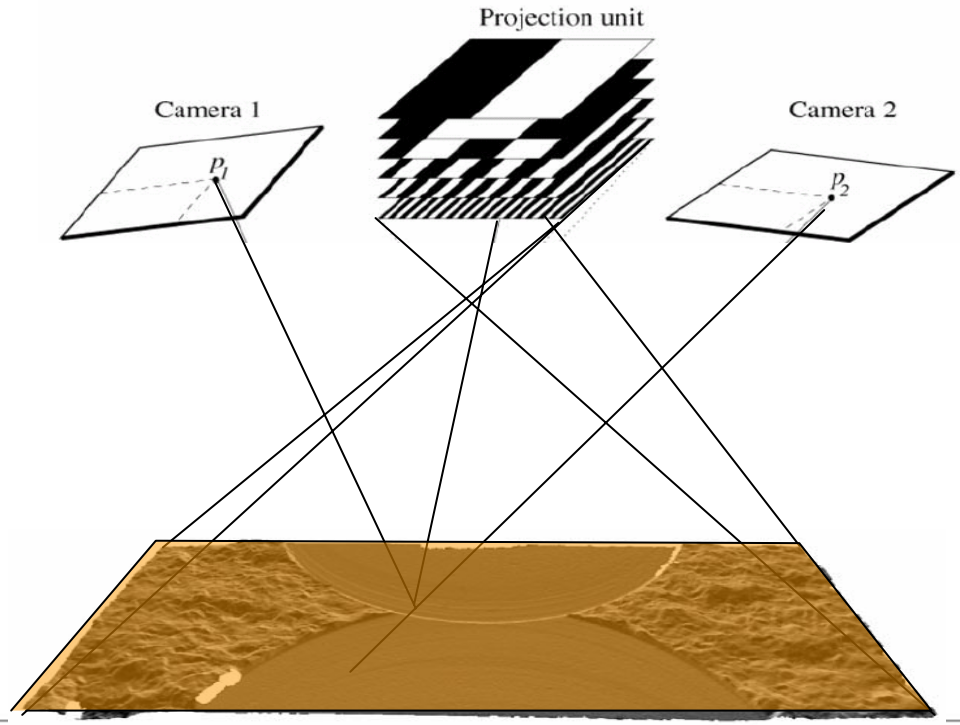
	Quartz		Feldspar		Biotite	
	Av.G Size (mm)	%	Av.G Size (mm)	%	Av.G Size (mm)	%
XY	1.25	25%	1.40	65%	0.60	10%
XZ	1.30	23%	1.63	68%	0.62	9%

Measurement of fracture deflection using 3D μCT scanner





Roughness measurement: 3D stereo-topometric scanner

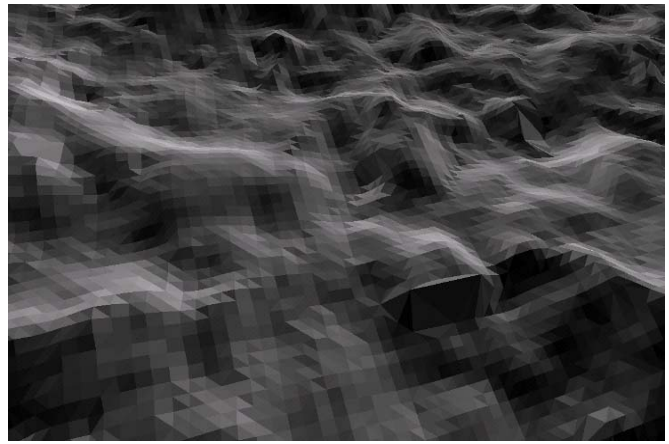


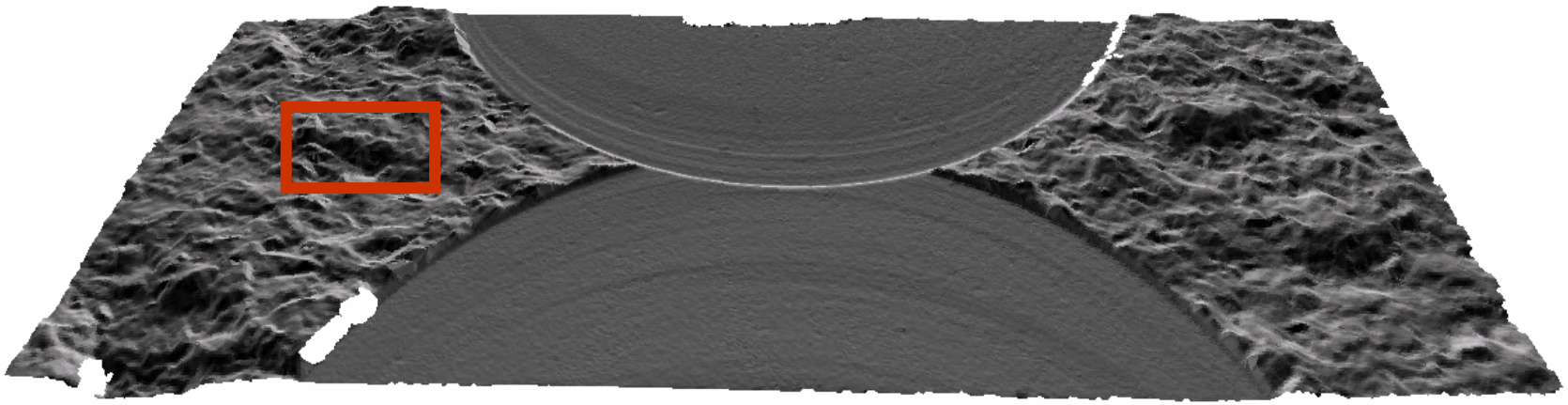
Measured Points	1 400 000
Measurement Time	1 second
Measuring Area from to	175 x 140 mm² 2000 x 1600 mm²
Point Spacing	0.12 - 1.4 mm

Grasselli G., Wirth J., Egger P., 2002, *Quantitative three-dimensional description of a rough surface and parameter evolution with shearing*, International Journal of Rock Mechanics and Mining Sciences, 36/6, pp. 789-800

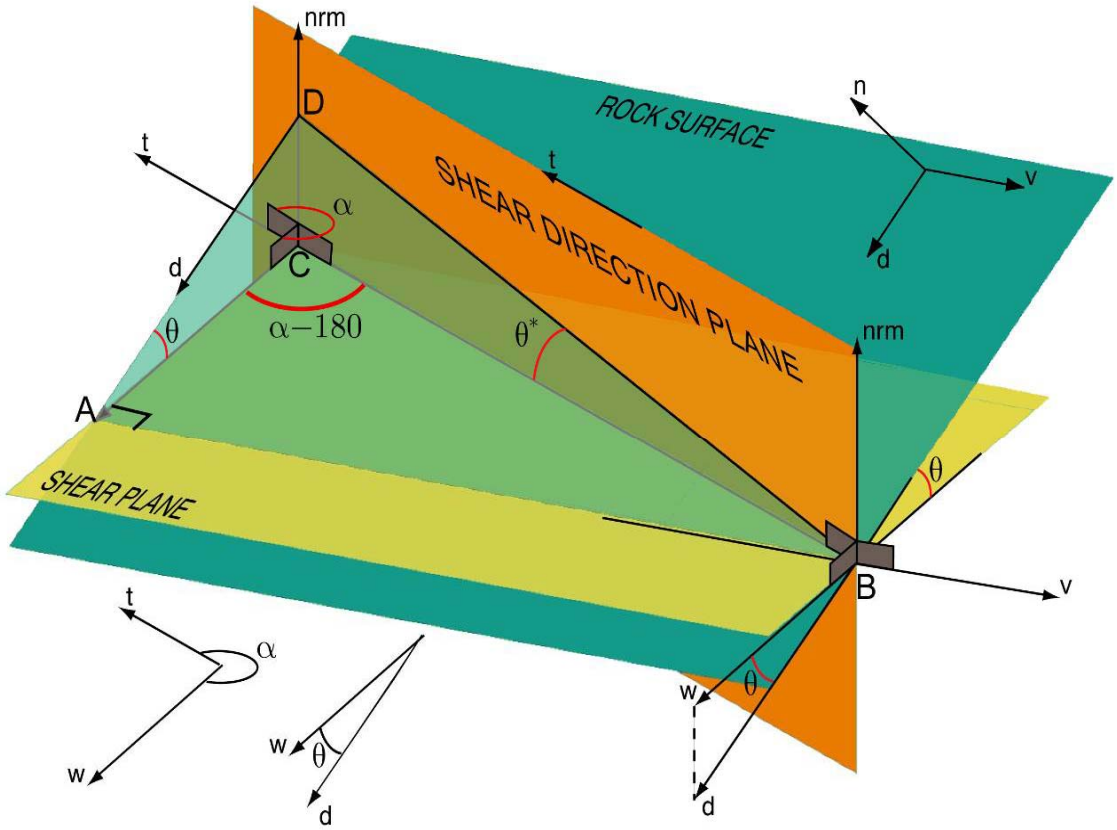
The 3CAD software (Wirth, 2002)

From measured point cloud to reconstructed surface by triangulation





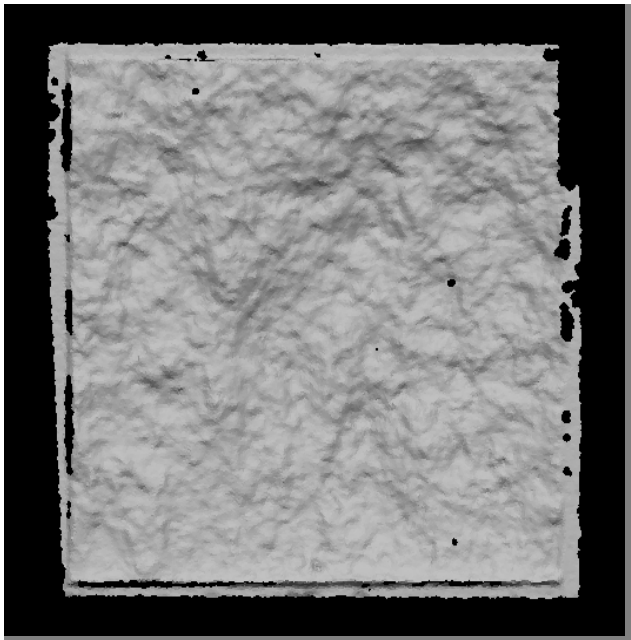
Geometrical identification of apparent dip angles as function of shear direction

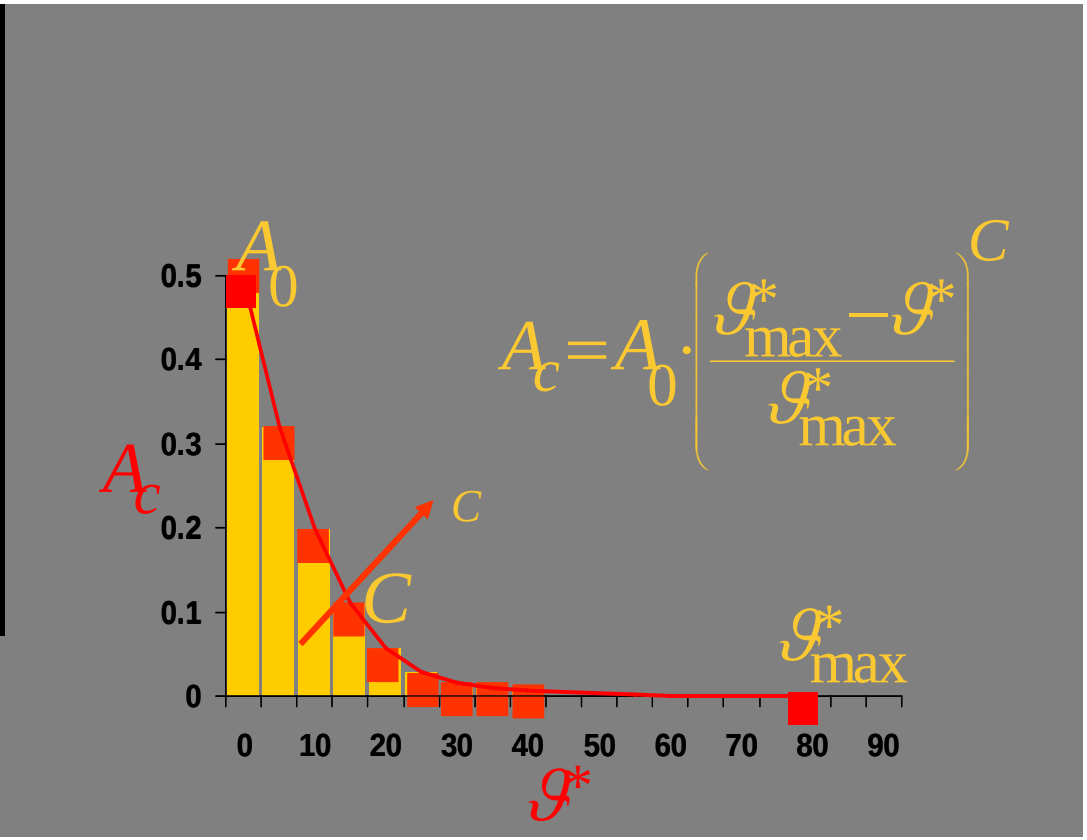


$$\tan\theta^* = -\tan\theta \cdot \cos\alpha$$

Grasselli G., Wirth J., Egger P., 2002, *Quantitative three-dimensional description of a rough surface and parameter evolution with shearing*, International Journal of Rock Mechanics and Mining Sciences, 36/6, pp. 789-800

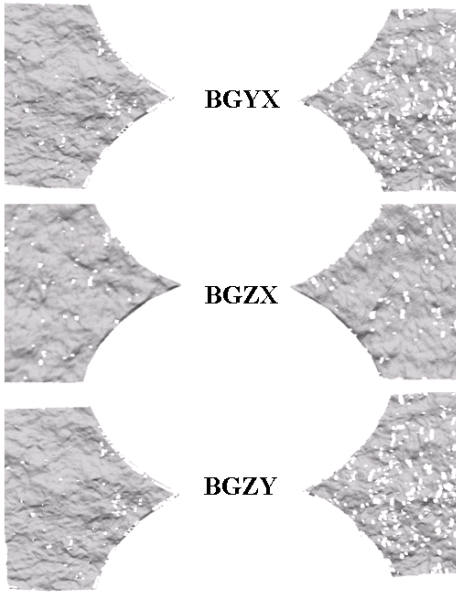
Roughness characterization

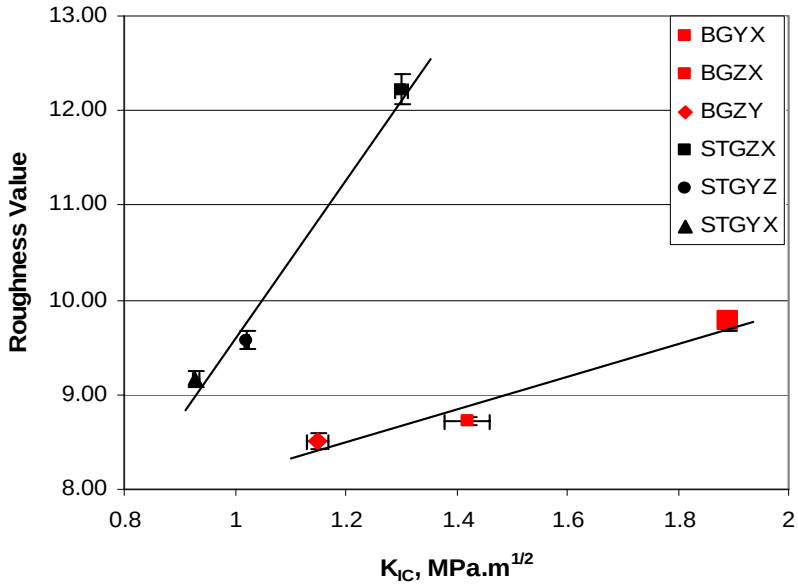


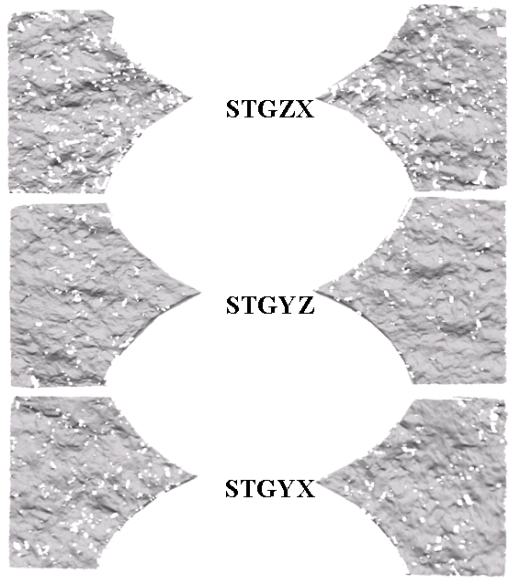


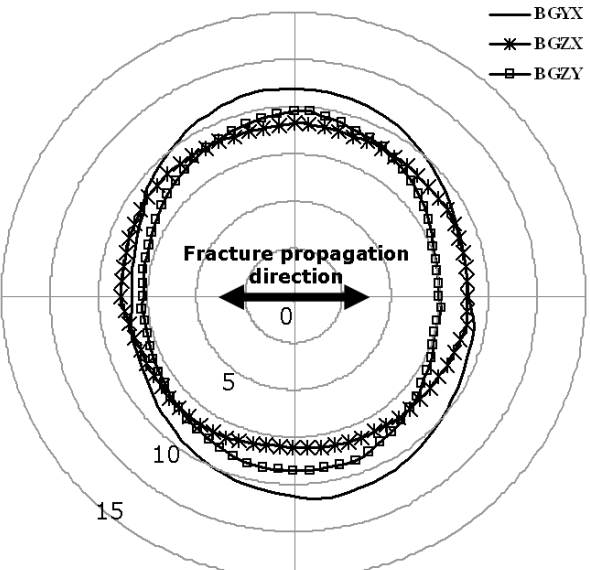
Grasselli G., Wirth J., Egger P., 2002, *Quantitative three-dimensional description of a rough surface and parameter evolution with shearing*, International Journal of Rock Mechanics and Mining Sciences, 36/6, pp. 789-800

Results on fracture roughness studies in granites with anisotropic K_{IC}



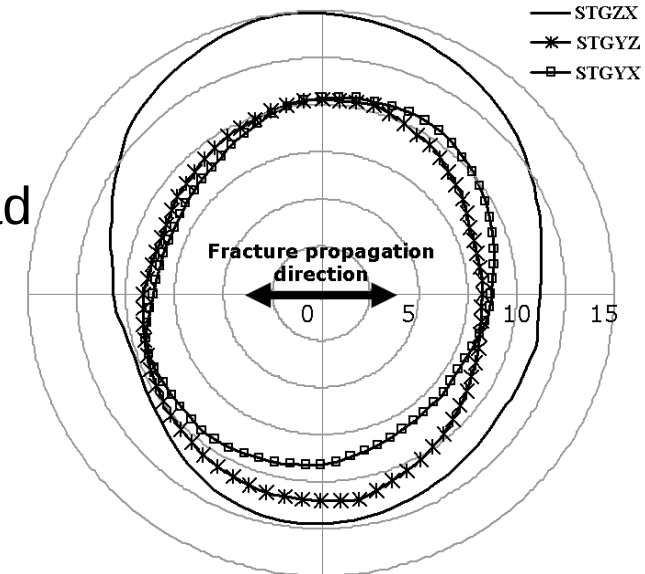






Barre granite

Stanstead granite



Final remarks

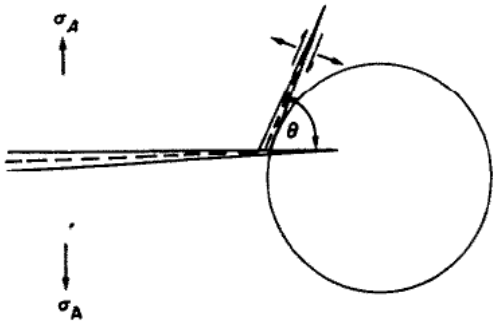
This study suggests that:

Fracture toughness and fracture roughness are closely interrelated with the specific microstructure of the rock.

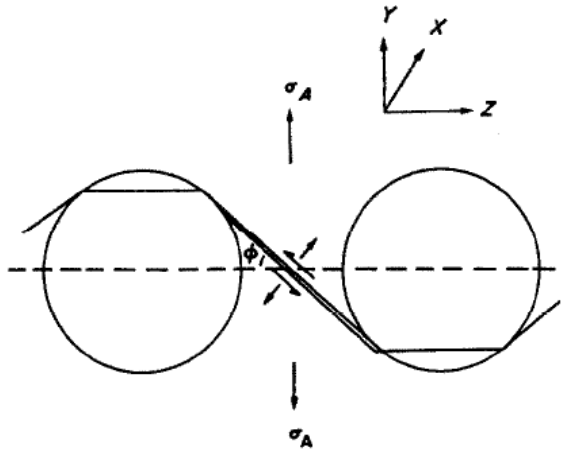
Fracture roughness can tell us something about the direction of propagation of the fracture.

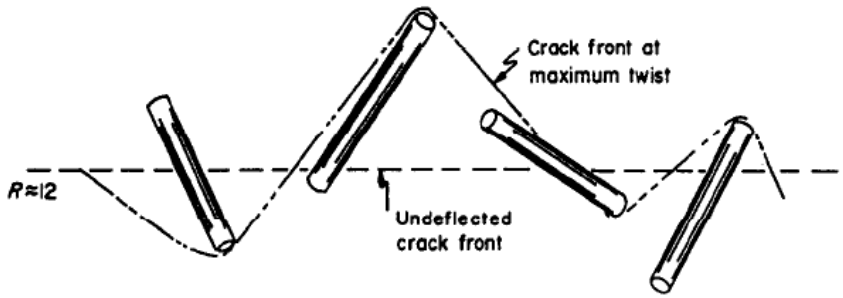
Microstructural features, grain morphology, and grain orientation are key elements for the understanding of how rocks fail.

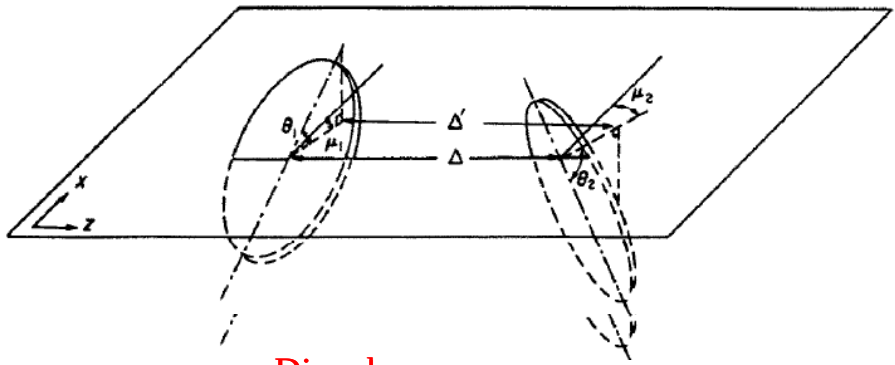
Roughness and toughness depends on grain morphology and aspect ratio



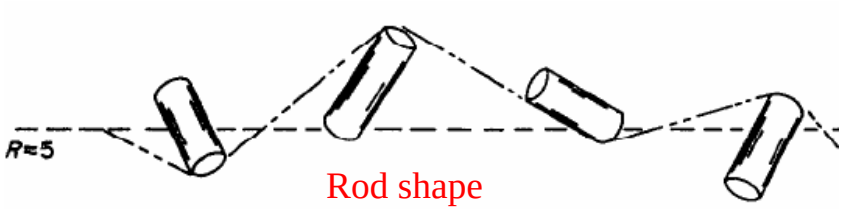
Spherical shape







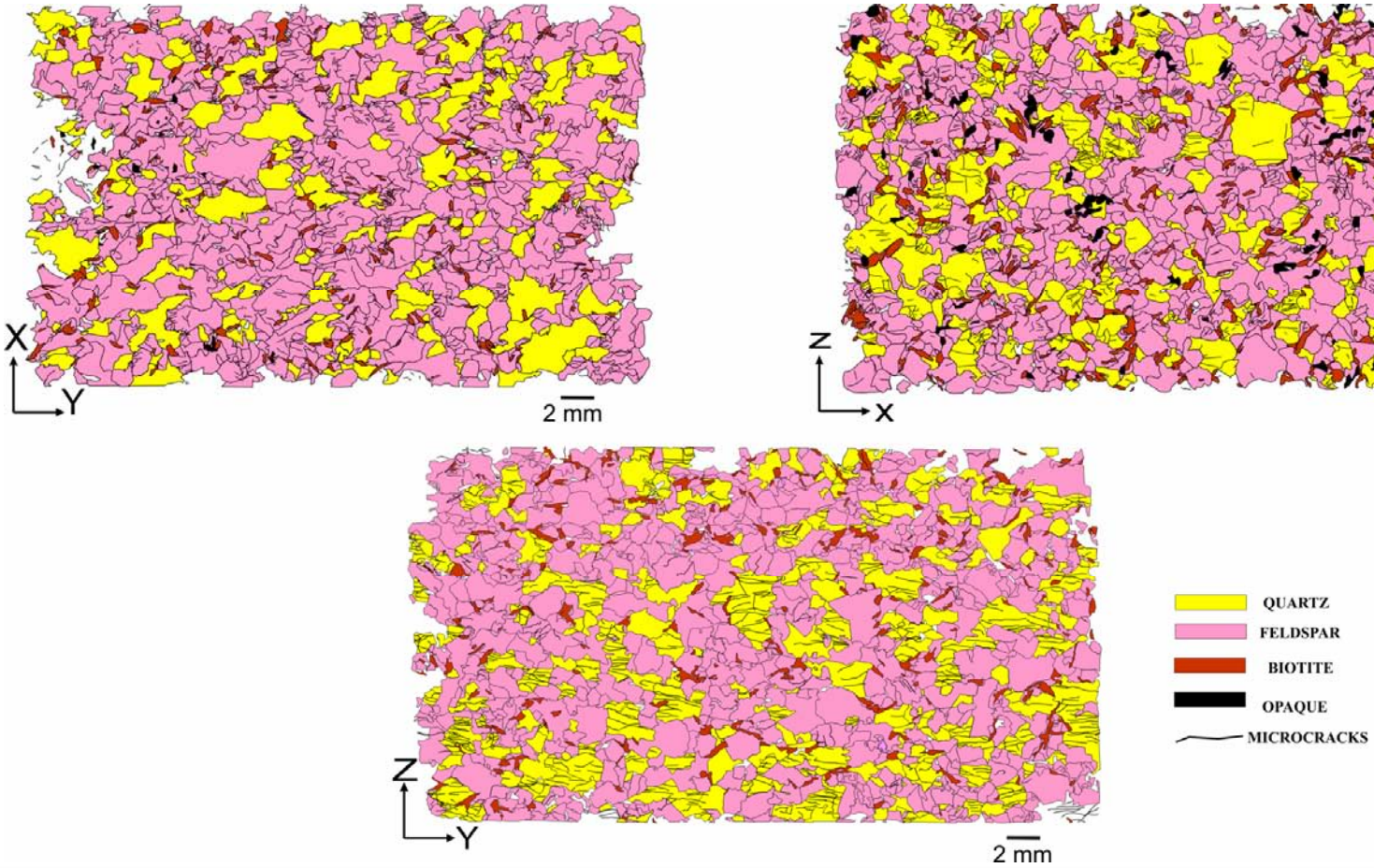
Disc shape



Rod shape

after Faber and Evans, 1982

Basic approach: microstructural characterization



Results on microstructural features of the rocks studied

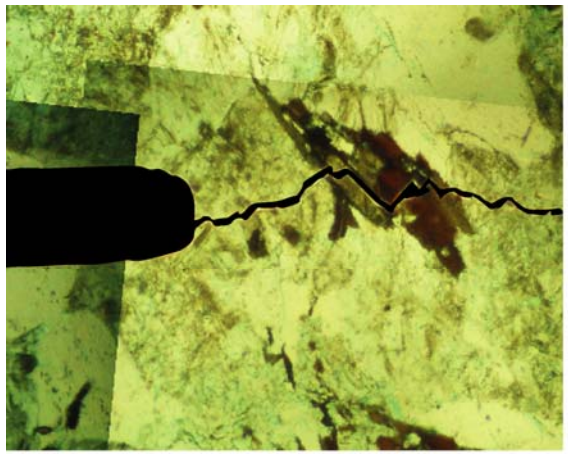
	Average grain (a) (mm)	(b) (mm)	Shape (a/b) (-)	No. grain (-)	ϕ (cm/cm^2)	Av. μ–crack length (mm)
Barre granite						
xy Plane	1.41	1.12	1.26	972	5.20	0.84±0.36
xz Plane	1.08	1.00	1.07	1534	4.46	0.68±0.25
yz Plane	1.38	1.10	1.25	1138	4.10	1.07±0.54
Stanstead granite						
xy Plane	1.17	1.14	1.03	893	5.20	1.38±0.52
xz Plane	1.35	1.11	1.21	668	4.80	1.08±0.45
yz Plane	1.28	1.13	1.12	771	2.80	0.94±0.41

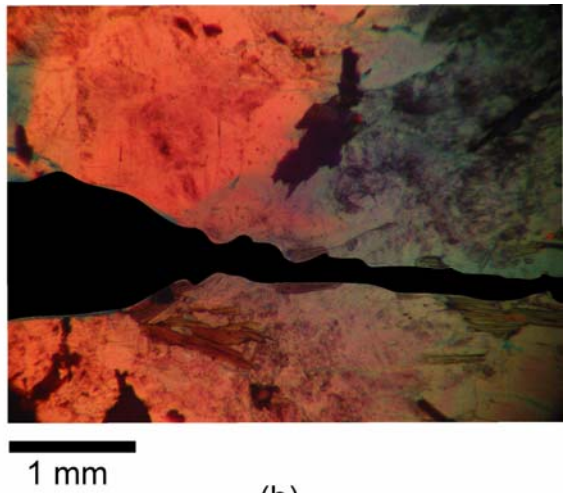
(a) = Ellipsoid's long axis, (b) = Ellipsoid's short axis, ϕ = microcrack density.

Future work

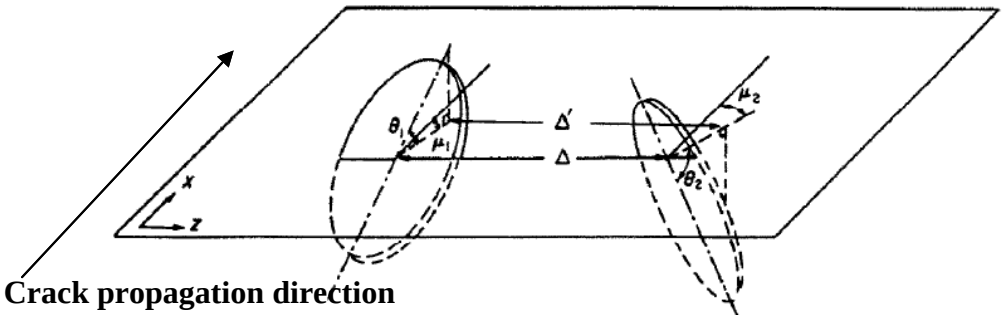
Barre granite

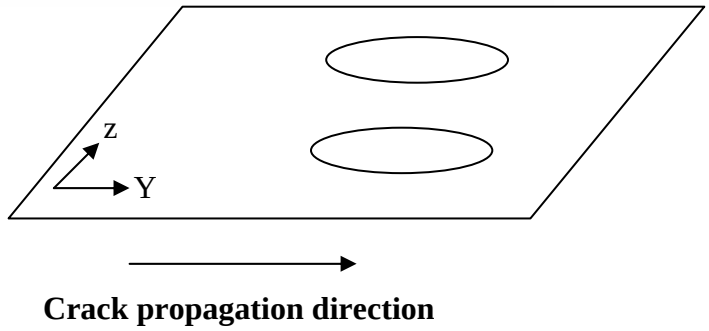
K_{xy}=1.89 MPa.m$^{0.5}$





K_{zy}=1.14 MPa.m$^{0.5}$

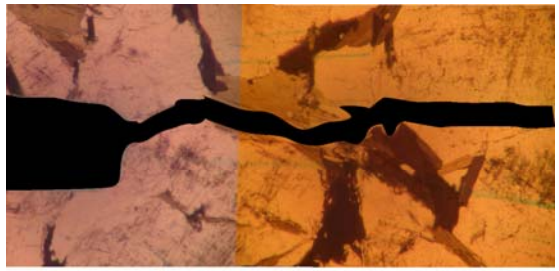




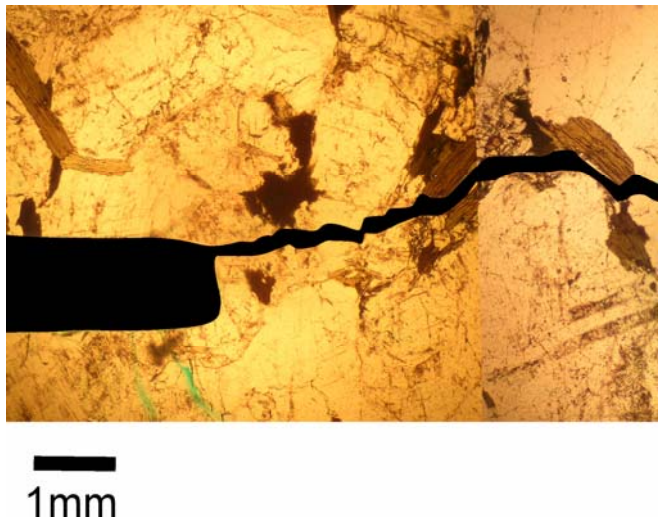
Stanstead granite

Mineral composition of the rocks studied

Minerals / Rocks	Quartz Av. G. Size (mm)	%	Feldspar Av. G. Size (mm)	%	Biotite Av. G. Size (mm)	%
Barre granite						
XY Plane	0.93	25%	1.10	75%	0.46	4%
XZ Plane	0.95	31%	0.81	61%	0.43	6%
YZ Plane	0.94	31%	0.96	65%	0.40	4%
Stanstead granite						
XY Plane	1.25	25%	1.40	65%	0.60	10%
XZ Plane	1.30	23%	1.63	68%	0.62	9%
YZ Plane	1.20	26%	1.45	67%	0.60	7%



K_{yx}=0.93 MPa.m$^{0.5}$



K_{zx}=1.43 MPa.m$^{0.5}$

Conclusion

1. **Barre granite being finer in grain size/smaller microcrack lengths shows aligned preferred microcrack/mineral fabric orientation thus reveals higher average K_{IC} (1.54 MPa $m^{0.5}$) than Stanstead (K_{IC}= 1.17 MPa $m^{0.5}$),**
2. **Barre also shows higher K_{IC} anisotropy (1.8) than Stanstead (1.5),**
3. **Both rocks show good correlation between K_{IC} values associated fracture roughness numbers,**
4. **Dimensions/damages associated with FPZ varies with direction fracture propagation in both rocks,**
5. **Micro-CT scan provides vital 3D information fracture roughness, macrocrack-microstructural fabric interaction/fracture deflection.**